Advanced Modeling of Particle Accelerators Using SciDAC Beam Dynamics Codes

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Summary

The goal of the SciDAC accelerator modeling project is to develop a new generation of terascale accelerator simulation codes that will allow the accelerator community to address the most challenging problems in 21st century accelerator design and optimization. This paper describes the beam dynamics component of the project. This effort involves the development of an extensible software framework for beam dynamics. This framework incorporates a set of interoperable, parallel software modules including space charge, beam-beam effects, wake field effects, collisions, and multi-species effects. Using this new capability, large-scale simulations are underway to improve the performance of existing colliders and high intensity rings, to design next-generation accelerators, and to advance the frontiers of accelerator science and technology.

Particle accelerators are critical to research in many fields including high energy physics, nuclear physics, materials science, chemistry and the biosciences. Accelerators have also been proposed that address national needs related to energy, the environment, and national security. The three-dimensional, multi-scale, nonlinear, and many-body aspects of accelerator design problems, and the complexity and immensity of the associated computations, add up to extreme technical difficulty. Advanced computing is essential to address these technical challenges.

SciDAC's accelerator modeling project is providing accelerator scientists with new terascale simulation codes that are making it possible to meet the technical challenges by performing important beam dynamics simulations that could not be performed previously.

In the areas of software and algorithm development, this project has achieved several "firsts" including development of:

• the first parallel beam-beam simulation code that includes, in a single application, weak-strong- and strong-strong models, finite crossing angle, longitudinal effects, and long-range collisions via a new shifted Green function algorithm.

• the first demonstration of a self-consistent 3D Langevin/Fokker-Planck computation on a parallel computer, calculating 3D damping and diffusion coefficients from first principles.

• the first parallel beam dynamics capability that combines 3D space-charge effects, high order optics, and wake field effects for parallel simulation of high intensity beams in linacs and rings.

The development of these new capabilities involved close collaboration of accelerator physicists with applied mathematicians and computer scientists, including those in the ISIC and SAPP programs. This includes:

• Collaboration with the APDEC ISIC to implement a multi-level Poisson solver that is based on the CHOMBO framework (P. Collela et al, APDEC).

• Integration of a parallel multigrid solver, exhibiting scaling up to 2048 processors, for modeling intense beams (A. Adelmann, LBNL, SAPP; C. Pflaum, U. Wurzburg).

• Development of a parallel wake field module (R. Samulyak, BNL, SAPP).

• Development of statistical methods for determining multi-dimensional phase space data from 1D wire-scanner measurements (K. Campbell and D. Higdon, LANL,SAPP).

• Development of new visualization techniques that combine volume rendering with point data (K-L Ma, UC Davis, SAPP), and visualizations for studying beam halo formation (C. Siegerist, LBNL).

• Development of parallelization and decomposition strategies, including use of the UCLA UPIC framework, to achieve high performance in beam dynamics simulations (V. Decyk, UCLA; J. Qiang, LBNL).

• Development of a prototype of a multi-language, extensible beam dynamics frame-work (J. Amundson, P. Spentzouris, FNAL).

The software developed is now being used to model beam dynamics in existing and proposed accelerators of DOE/SC, and as a tool to explore the complex dynamics of intense beams. Parallel simulations, run on the NERSC IBM/SP, include:

• Simulation of beams in the Tevatron to study long-range beam-beam effects and help improve performance; and simulations of colliding beams in the LHC to study the performance of a US luminosity monitor.

• Simulations and experiments at the FNAL booster, and simulations of the BNL booster, to understand space-charge effects and beam loss in high current rings.

• Exploring, through large-scale simulation, the stability of nonequipartitioned beams .

• Modeling e^--cloud effects in the LHC using software developed in the Advanced Accelerator portion of this SciDAC project.

Our near-term plans in beam dynamics software development and applications include: (1) Continued development of the parallel beam dynamics framework for the accelerator community; (2) Using the framework to combine linac modeling with modeling multi-turn injection in a high intensity ring, with application to the FNAL and BNL injector complexes; and (3) Extension of the first-principles Langevin approach to intrabeam scattering and to model electron cooling at FNAL and BNL.

To accomplish these goals will require continued support for this SciDAC project in FY04 and FY05, along with continued support for our collaborators in the ISIC and SAPP programs. The complexity of our computer models and target applications, particularly simulating high intensity beams in rings, requires substantial computational resources. Our project allocation requests are 7M hrs in FY04 and 10M hrs in FY05.

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